LHCb Silicon Tracker electronics: from R&D to preproduction

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Abstract

The LHCb Silicon Tracker consists of the Trigger Tracker located in front of the magnet and the Inner Tracker behind the magnet. While both tracking stations have a quite different appearance due to geometrical constraints, the basic working principle and building blocks for sensors and electronics are identical therefore simplifying R&D and upcoming production.

This paper describes the development and transition to the preproduction phase of the Silicon Tracker components with focus on the electronic modules. We present the final mechanical design of the detector modules for both the Trigger Tracker and the Inner Tracker and the design of the associated readout hybrids. In addition, performance data for the first preseries of digitizer boards for the Silicon Tracker is shown and short information about electronic modules under common development within LHCb is given.

I. INTRODUCTION

LHCb is a dedicated experiment at the future LHC collider for studying CP-violation in the b-quark sector. It has been designed as a single-arm forward spectrometer with a dipole magnet and an acceptance angle of 300 mrad in the bending plane. Due to the expected large number of tracks, the detector tracking system has been divided in an Outer Tracker based on straw tubes and an Inner Tracker, covering the high occupancy area around the beam pipe. For improved tracking performance, an additional tracking station called 'Trigger Tracker' has been introduced between the RICH1 detector and the magnet. A second RICH detector trails the Inner Tracker stations which are surrounded by a straw tube Outer Tracker to cover the full acceptance angle. Following the calorimeters is the muon tracking detector while the precise location of vertices is done with the VELO detector situated around the interaction region.

II. DESIGN OF THE SILICON TRACKER

The baseline technology for the Silicon Tracker was chosen to be silicon strip detectors. To maintain excellent momentum resolution while keeping the number of readout channels low, the strip pitch was chosen to be in the order of 200 µm. To compensate the higher noise contribution of longer strip detectors, the thickness of the strip detectors varies as well as the length of a detector module. While 320 µm are sufficient for modules consisting of one sensor with a strip length of 11 cm, 410 µm thick silicon sensors are used for the 2-sensor modules. For the even longer detector modules of the Trigger Tracker, a thickness of 500 µm has been chosen to ensure a S/N ration of more than 10 after an irradiation dose equivalent to 10 years of LHC operation [1].

A. Sensor ladders: detectors + readout hybrid

For the Inner Tracker, the sensor ladders consists of either one single sensor or two sensors connected in series, therefore doubling the strip length. The sensors are positioned inside a U-shaped carbon fibre composite, which supports cooling via its high heat transfer capability. This reduces the leakage currents and consequently the induced shot noise, which is particular important after irradiation to prevent self-heating and thermal runaway of a silicon sensor. The uniform sensor pitch of 198 µm is adapted to a 3-chip frontend hybrid via an alumina pitch adapter. The frontend hybrid is a 4-layer polyimide design, which carries 3 Beetle 1.3 readout chips. As each chip has 128 charge preamplifiers connected to an internal analogue pipeline, this hybrid can handle all 384 strips of one sensor module.

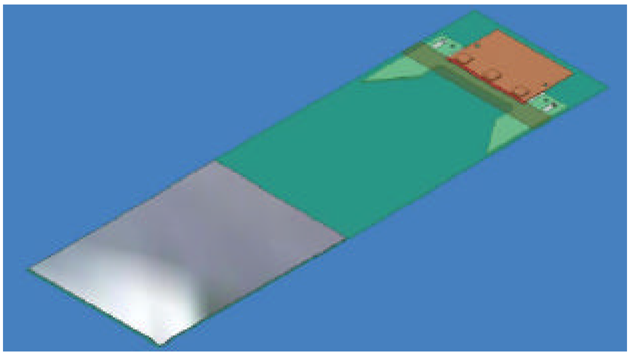

Figure 1: illustration of a 2-sensor IT detector module

A Trigger Tracker module is based on sensors of a thickness of 500 µm and a strip pitch of 183 µm with 512 strips in total. Each module runs the full height from the +Y- to the – Y-limit of the acceptance at the z-position of the Trigger Tracker. While this module is mechanically one piece, it consists of two electrically separated sections ('half-modules'), which are assembled and tested separately before being joined together for mounting into the Trigger Tracker station. To cover the full length in Y-direction with sensors, 14 sensors per module or 7 sensors per half-modules are needed.

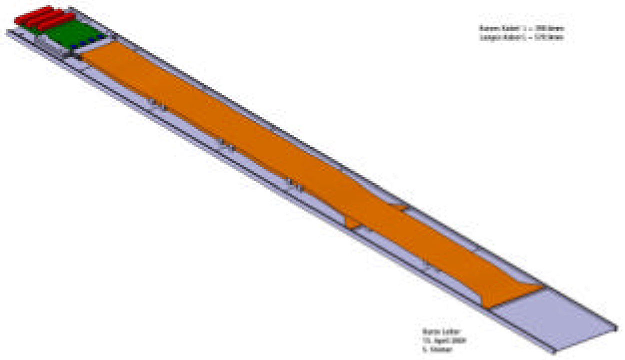

Figure 2: illustration of 4-3 half module of the TT station

As neither expected strip occupancy nor strip capacitance and in consequence the strip noise allows operation of 7 sensors connected in series, a half-module is divided in one 3-sensor section and a 4-sensor section with the 4-sensor section located at the station's frame. For even more reliable operation the 3-sensor sections located directly around the beam pipe are even further separated into one 2-sensor section and a single sensor section. Each section is connected to its own readout hybrid with 4 Beetle 1.3 therefore capable of handling all 512 strips of these modules. To prevent the readout hybrids from being placed inside the acceptance angle of the detector, the 3-, 2- and 1-sensor sections are connected to polyimide flexcables, which connect the sensors to their associated readout hybrids, which are all located on the station frame outside the acceptance area. In addition to the minimization of material inside the detector, this also simplifies mounting and cooling of the readout electronics. In contrast to the Inner Tracker modules, the Trigger Tracker sensors are only held via carbon fibre rails glued to the sensor edges. The readout hybrid of the outermost section, which is the 4-sensor part, is glued onto a aluminium nitride carrier plate of the same width, which allows it to be glued into the extension of the carbon fibre rails. As this carrier plate is bolted to the surrounding mechanical support, its precision holes define the exact position of the associated sensor module. The readout hybrids of the inside silicon sensor sections are stacked onto the hybrid sitting on the aluminium nitride plate. As their exact position is not important anymore, they are mounted on copper support plates for best heat conductivity.

B. Service Box

As the output data from the Beetle readout chips is analogue, the transmission up to the analogue-digital conversion has to be as short as possible to minimize any loss of signal quality. As the radiation levels increase with proximity to the beam pipe, a compromise between short connections to the AD converters and low radiation levels has to be found, as any excessive radiation will limit the number of usable devices. It has been determined, that a cable length of 5 m will allow any support electronics to be mounted outside the detectors acceptance for the case of the Inner Tracker stations. For the Trigger Tracker, a cable length of 5 m allows for a location of the 'Service box', which is comparable to the radiation levels for the proposed locations of the Inner Tracker Service boxes. For connecting the readout hybrids to the Service boxes, a SCSI cable with 68 pins in being proposed, as these type of cable is specified for high bandwidth transmission of differential signals. In addition, these cables can be assembled with the necessary connectors by the industry.

The 'Service box' contains the necessary electronic components for supplying the readout hybrids with power and timing signals. It also includes the line receivers for the Beetle analogue data [2], the 8-bit ADCs [3], the CERN Gigabit Optical Link serializers (GOL) [4] and the VCSEL diodes [5] for coupling the gigabit data stream into an optical fibre [6]. The latter components are all located on the so called 'Digitizer Board'. As one Digitizer Board will be associated to a single readout hybrid, it has a 3-fold or a 4-fold modularity depending if the Digitizer Board is used with a Inner Tracker hybrid or a Trigger Tracker hybrid.

As the GOL serializers need a low-jitter clock, which cannot be taken directly from the TTC network, a QPLL low-jitter PLL chip [7] was included in the Digitizer Board design. To make use of the 'DataValid' signal from the Beetle, which is a digital signal being synchronous to the analogue data, a shift register is implemented in a small rad-hard antifuse FPGA []. It delays the digital signal by the same number of clock cycles as the analogue data is delayed by the AD-conversion before reaching the GOL serializer. By doing this, the DataValid signal can be used to control the TransmitEnable signal of the GOL to initiate IDLE frames between readout frames. This makes it possible for the deserializer on the receiving side to resynchronize on the data stream without any user interaction in case of any loss of lock. The VCSEL diode has been chosen in favor of an integrated multi-fibre transmitter due to its inherent radiation tolerance. The chosen device also includes a metal receptacle serving both as a robust mechanical mount for the diode and a solid coupling to the fibre .

Additional elements of the Service box are the Control Card and the backplane of the Service box. While the backplane only provides the power supply and timing distribution for the Digitizer Boards and the Beetle readout hybrids, the Control Card has to provide the timing signals and the correct phase relation between them. To do this, it carries a TTCrq mezzanine [8] as interface to the TTC network and two SPECS slave mezzanines [9] for slow control signals like I2C and TTL.

C. Optical Readout Link

The digital optical readout link has been chosen due to its capability to operate with high data rates while being rather insensitive to electromagnetic interference like external pickup or crosstalk. The decision of using digital over analogue transmission has the advantage of using the radiation hard CERN GOL device and commercial off the shelf gigabit transmission devices like multi-channel optical receivers and gigabit deserializers.

To unify the used cable types within LHCb, a common approach between all subdetectors using several multi-fibre ribbon cables packed in a single tube is being followed by a group at CERN. This would not only decrease the number of different cables ordered but als o decrease the price and make installation more simple than in the cases of using different cables for each subdetector.

The use of a single cable type for all subdetectors is supported by the fact, that the subdetectors using optical transmission have decided to use the same optical receiver card, which is based on a SNAP12 compatible 12-channel receiver [10] and the TLK2501 deserializer [11]. The so called O-Rx card is under development at Physikalisches Institut, Universität Heidelberg [12].

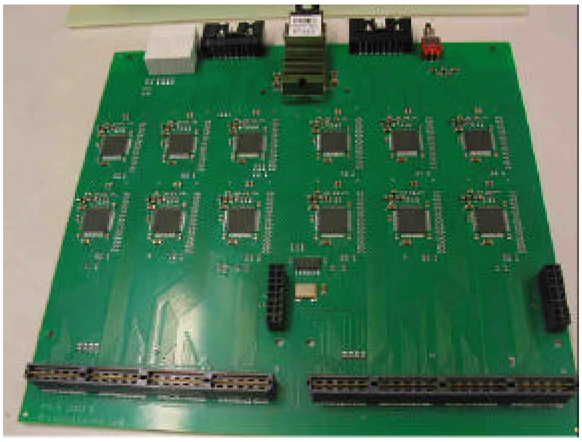

Figure 3: O-RX card

D. The TELL1 board

As most of the subdetectors face similar requirements at the level of the L1 readout electronics, a common L1 readout board, the TELL1 board, is being developed by the EPF Lausanne [13]. Its purpose is to combine the incoming data from different sources and perform basic data processing like hit finding and clustering in the case of the Silicon Tracker. As these algorithms are located in 4 so-called Link-FPGAs, the TELL1 board is very flexible to be adapted to the specifc subdetector needs. An integrated FIFO memory temporarily stores the event data until receipt of a Level1-accept signal, which releases the data for transmission over a gigabit ethernet interface to the DAQ processor farm.

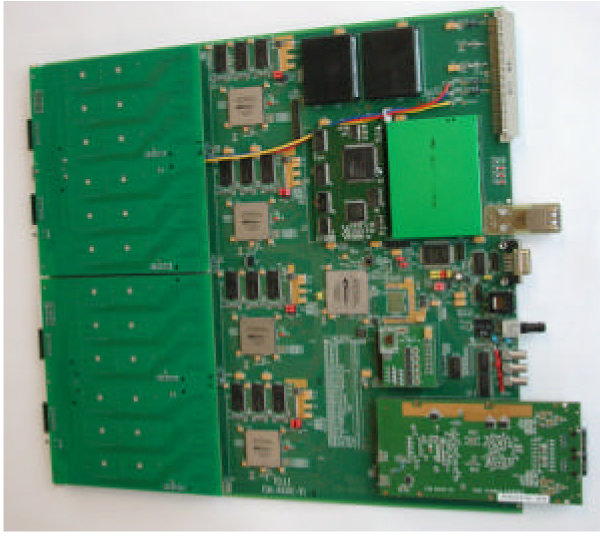

Figure 4: TELL1 module fully equipped with mezzanines

III. Status of Hardware

A. Sensor Ladder

During a testbeam at CERN X7 in Summer 2003, the estimated performance of the silicon sensors with 410 µm and 500 µm thickness was verified [14]. In addition, another testbeam period in Summer 2004 confirmed the possibility of using polyimide flexcables between sensor and readout hybrid with S/N degradation only related to the additional capacitive load of the cable [15].

A first prototype half-module for the Trigger Tracker is scheduled to be completed until end of the year. In addition, this module will be mounted into a mechanical scale mock-up of the Trigger Tracker station to include thermal and mechanical tests as well.

B. Optical Readout Link

The first preseries of 17 Digitizer Boards has been produced in July 2004. To collect some experience with the companies, the same companies selected for series production also produced the preseries, which is described here. After PCB manufacturing, the boards were immediately given to another company for component population and soldering. To check the integrity of the BGA soldering, all 5 BGA packages on all 17 boards were scanned with X-ray monitoring for any solder defects. Out of just over 10000 solder balls, none was found to be bad.

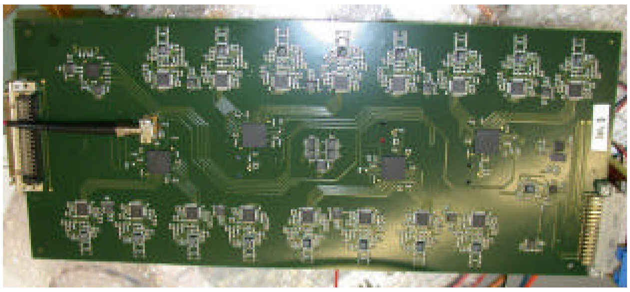

Figure 5: TT Digitizer Board

After final manual integration of the VCSEL diode, first tests showed immediately a good link synchronization with a O-RX card prototype. With the clock and trigger being supplied via a small TTC network in the laboratory, the lock state of the QPLL was verified to be stable. Another check was done on the single sided analogue signal just in front of the ADC, which is the output of the differential line receiver. Tests with a 10 m long cable showed a sufficiently long flat top of a Beetle output bin of 16 ns compared to the length of such a bin of 25 ns. This flat top provides enough phase timing margin for the sampling clock with respect to the Beetle clock.

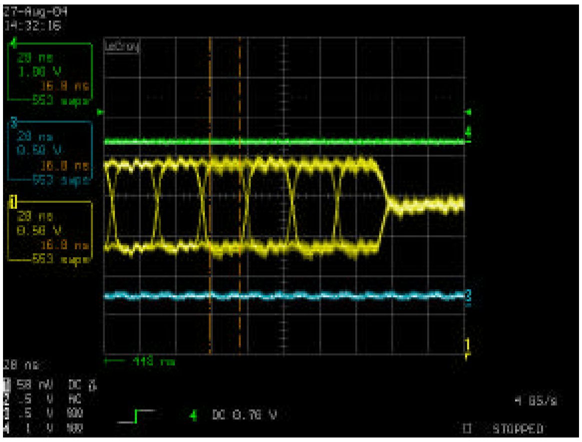

Figure 6: eye pattern for the Beetle header after 10 m cable

A proper bit error rate test performed by D. Wiedner (Physikalisches Institut, University Heidelberg) over a period of 3 days showed no bit errors.

C. TELL1

The first TELL1 prototypes performed as expected with injected tests patterns and a small preproduction batch is under production for distribution to the participating institutes for start of subdetector-specific firmware development and testing. For further informations, check on the TELL1 website [13].

IV. RADIATION

The readout hybrid is composed of Beetle chips and passive components and therefore being assumed to be radiation hard. For the location of the Service box, the radiation levels are comparably low, but may still cause problems in certain devices. With maximum numbers for TID of 15 krad and 1 MeV n equivalent fluence of $2{\cdot}10^{12}$ n/cm^2 for 10 years of LHC operation, all active components and optical devices have to be qualified according to LHCb radiation qualification policy [16]. This was done by the LHCb-ST group for the AD8129 line receiver, the TSA0801 ADC, the ULM Photonics VCSEL diode and the optical fibre [17]. All of these components were determined to be qualified for usage in the LHCb-ST Service box environment.

VI. CONCLUSION

Prototypes for different silicon strip sensor ladders corresponding to the different ladder geometries forseen in the LHCb Silicon Tracker have been characterized during CERN testbeams in 2003 and 2004. These tests included tests with polyimide flexcables between the sensors and the readout hybrid and confirmed the functionality of the Trigger Tracker design.

A Digitizer Board has been designed, which receives the analogue data from one readout hybrid for digitization, gigabit encoding and transmission via VCSEL diodes. In addition, the Digitizer Board also supplies power, TTC signals and slow control signals to each hybrid therefore serving as the only connection of a hybrid to the LHCb experiment. The first preseries production lot is under tests and shows performance as expected from the earlier version prototype modules. As a consequence, these preseries units will be used in a scale mock-up of the Trigger Tracker station, which is under construction in the University Zürich for mechanical, thermal and electronic testing of preproduction and later production testing of TT-station half modules. The Digitizer Board has also been shown to provide data compatible to the O-RX card, which is forseen as the optical input interface of the TELL1 preprocessing card. All these tests were performed with an actual Beetle 1.3 hybrid supplied with fast signals from a small TTC network set up. The active and optical components located on the Digitizer board have been qualified to radiation levels expected at the planned Service box locations for 10 years of LHC operation.

VII. References

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